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(54) DMD DISPLAY SYSTEM

(57) A display system includes a deformable mirror device 31 arranged to direct spatially modulated light onto a display screen. The deformable mirror device 31 includes a number of mirror elements arranged to direct light of different wavelengths onto a display screen. The mirror elements may be arranged to direct light of different wavelengths onto the display screen at different times. The mirrors of array 31 reflect either blue light (35) on the light from mirrors of array 33, this being alternately red (39) and green (37).

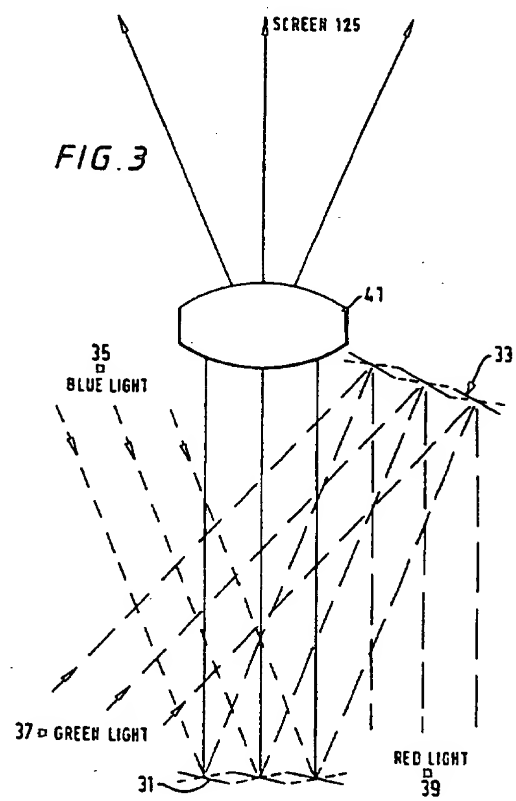
Luminance changes are caused by controlling the ratios between ±10° positions of mirrors 31 and the no light (black) reflected 0° position.

The array may be formed of two 1 dimensionally or 2 dimensionally interleaved sub-arrays respectively reflecting one color and alternately the other two.

The array may be formed of three interleaved sub-arrays respectively reflecting the three colors.

Each mirror may be mounted to pivot about two orthoganal axis, the three color beams being directed onto the mirrors at different angles.

FIG.3



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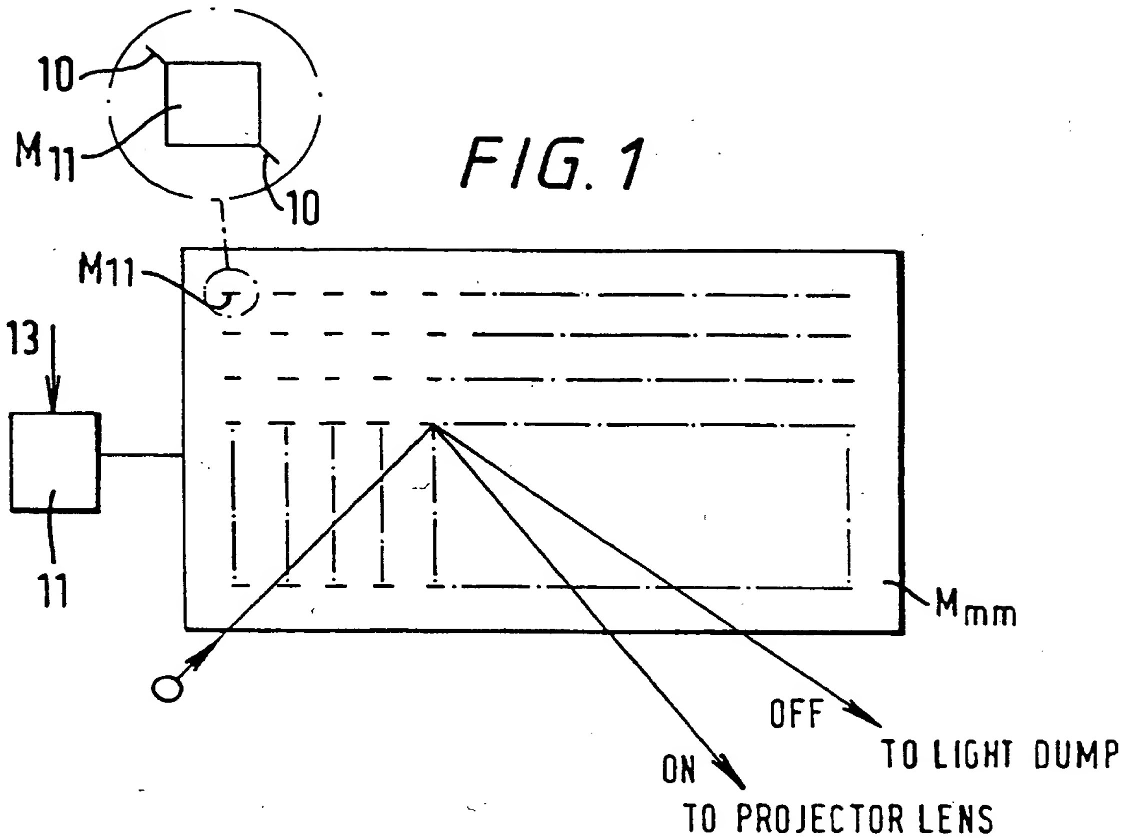
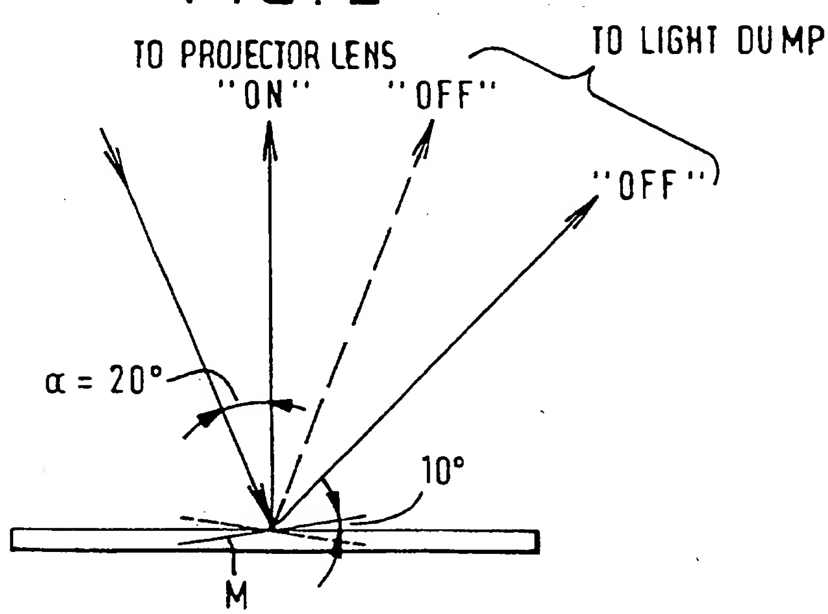

10
M_{11}
10
M11
13
11
M_{mm}
OFF
TO LIGHT DUMP
ON
TO PROJECTOR LENS

FIG. 1

FIG. 2


TO PROJECTOR LENS
"ON"
"OFF"
TO LIGHT DUMP
"OFF"
α = 20°
10°
M

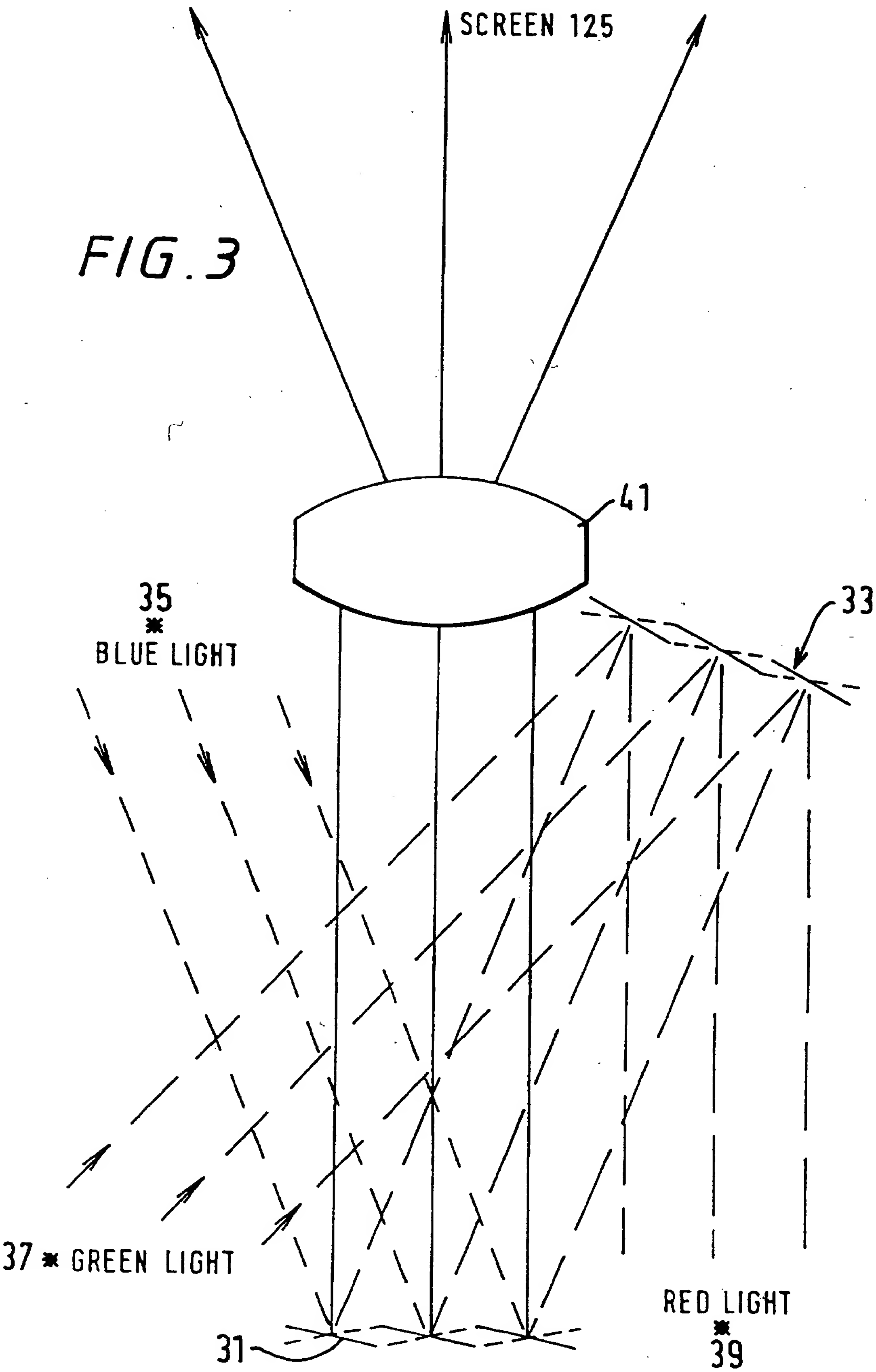


FIG. 3

FIG. 4

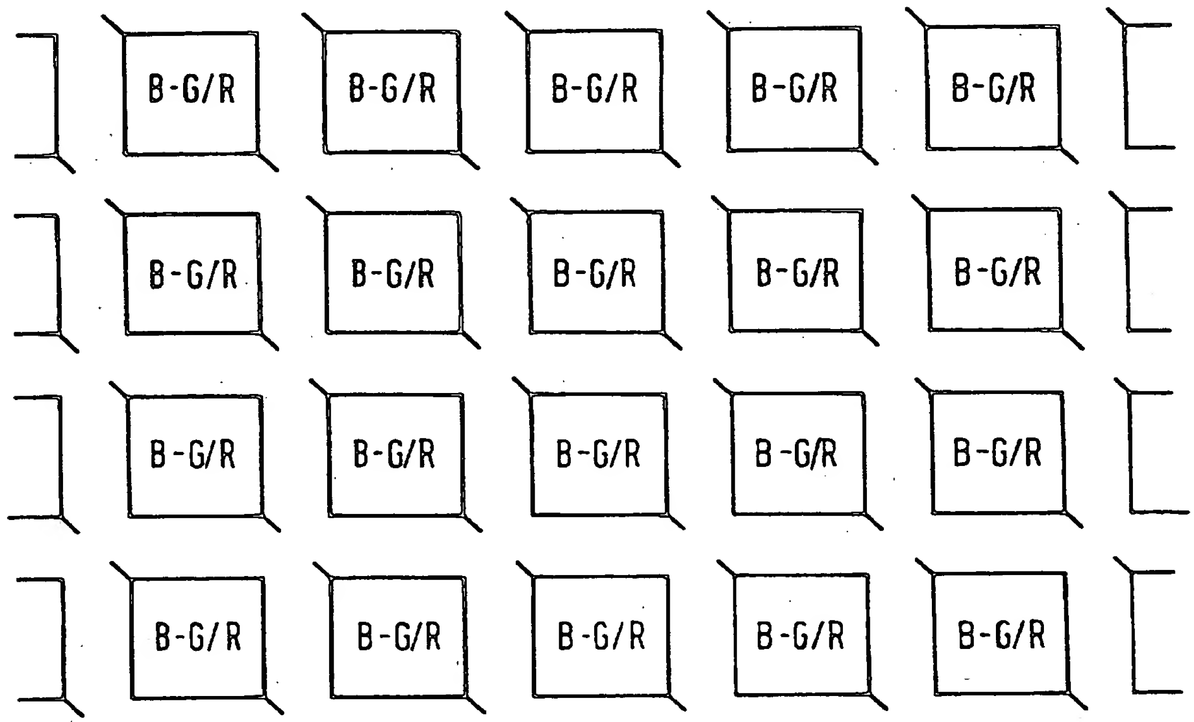


FIG. 5

SYSTEM TYPE	FORM OF SEQUENCE
FILTER WHEEL COLOUR	BBBBBBBBBBBBBBBGGGGGGGGGGGGGGGRRRRRRRRRRRRRRR
DMD COLOUR	BBRRGGBBRRGGBBRRGGBBRRGGGRBGGRRBBGGRRBBGGRRBB

FIG. 6

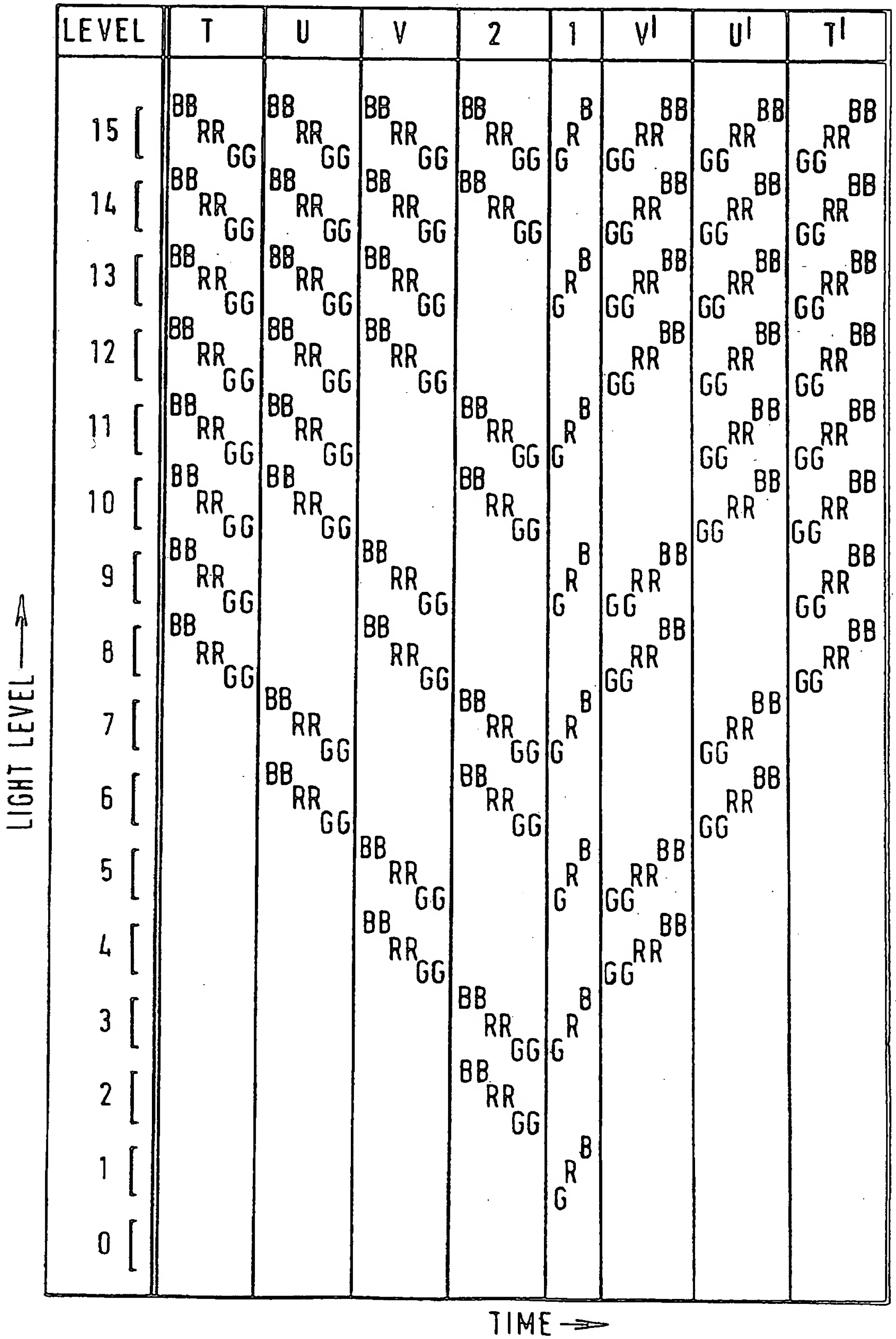


FIG.7

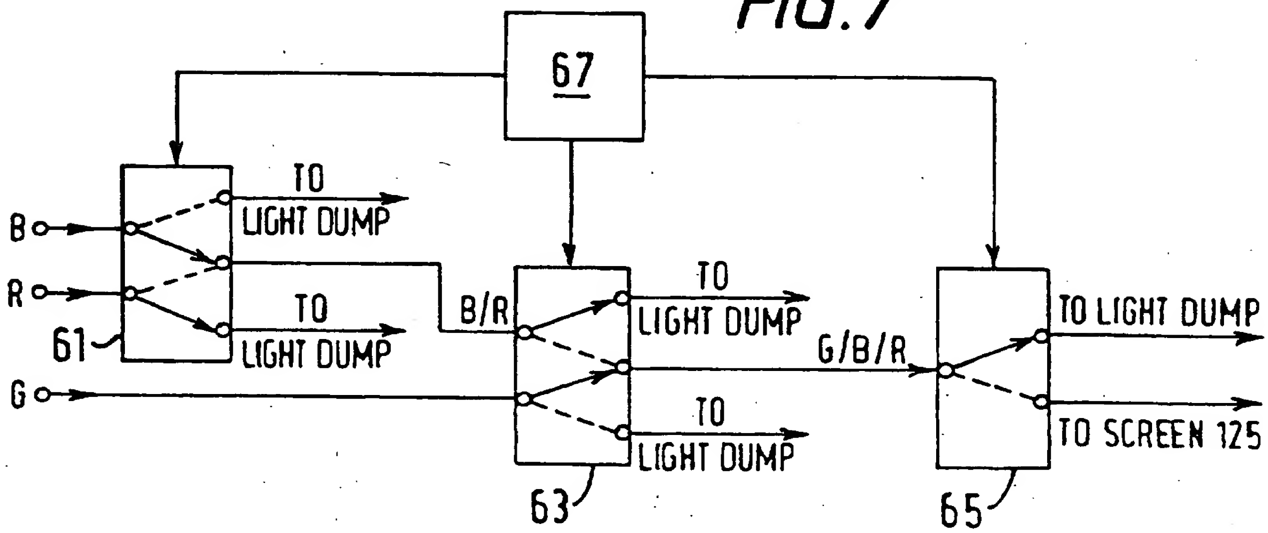
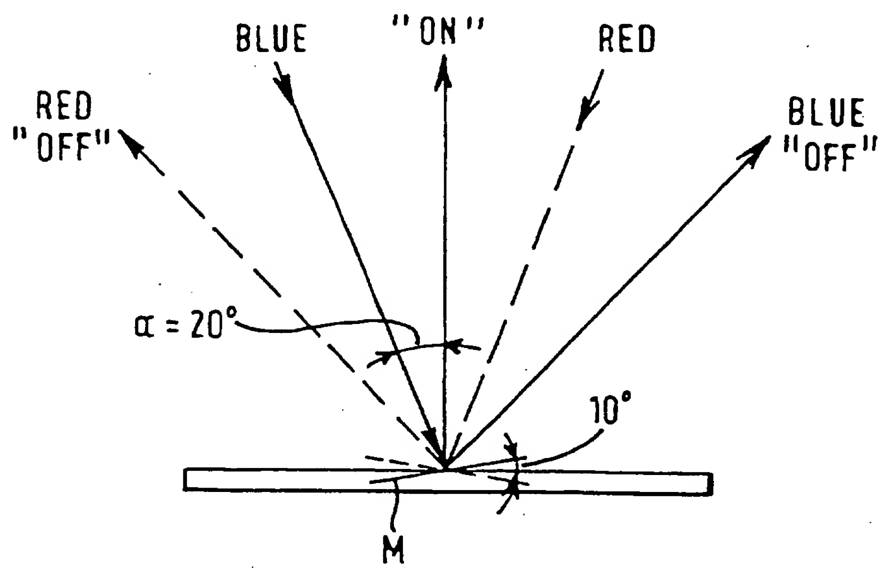

67
TO
LIGHT DUMP
B
R
TO
LIGHT DUMP
61
G
B/R
TO
LIGHT DUMP
TO
LIGHT DUMP
63
G/B/R
TO LIGHT DUMP
TO SCREEN 125
65

FIG.16


BLUE
"ON"
RED
RED
"OFF"
BLUE
"OFF"
α = 20°
10°
M

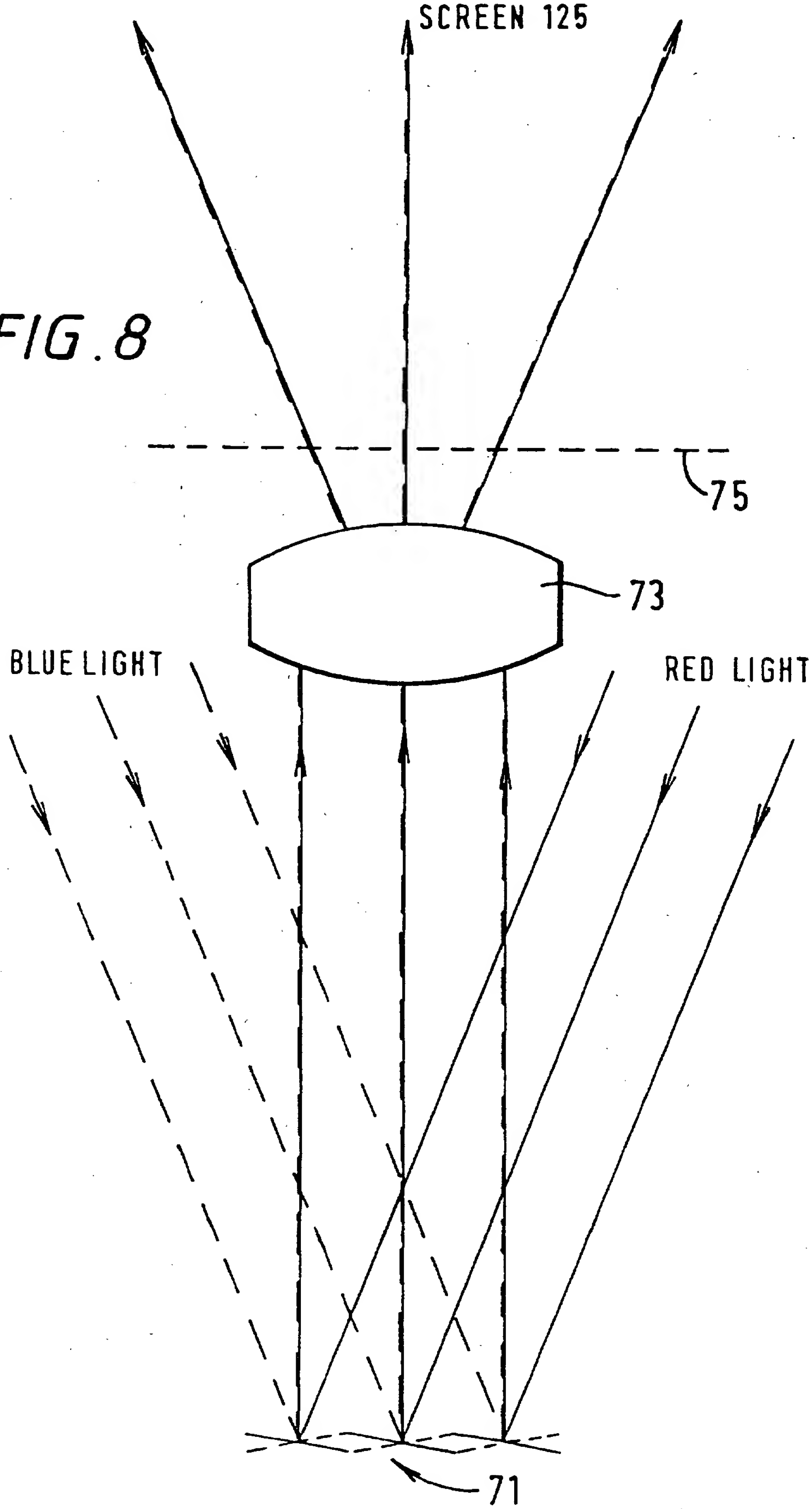


FIG. 8

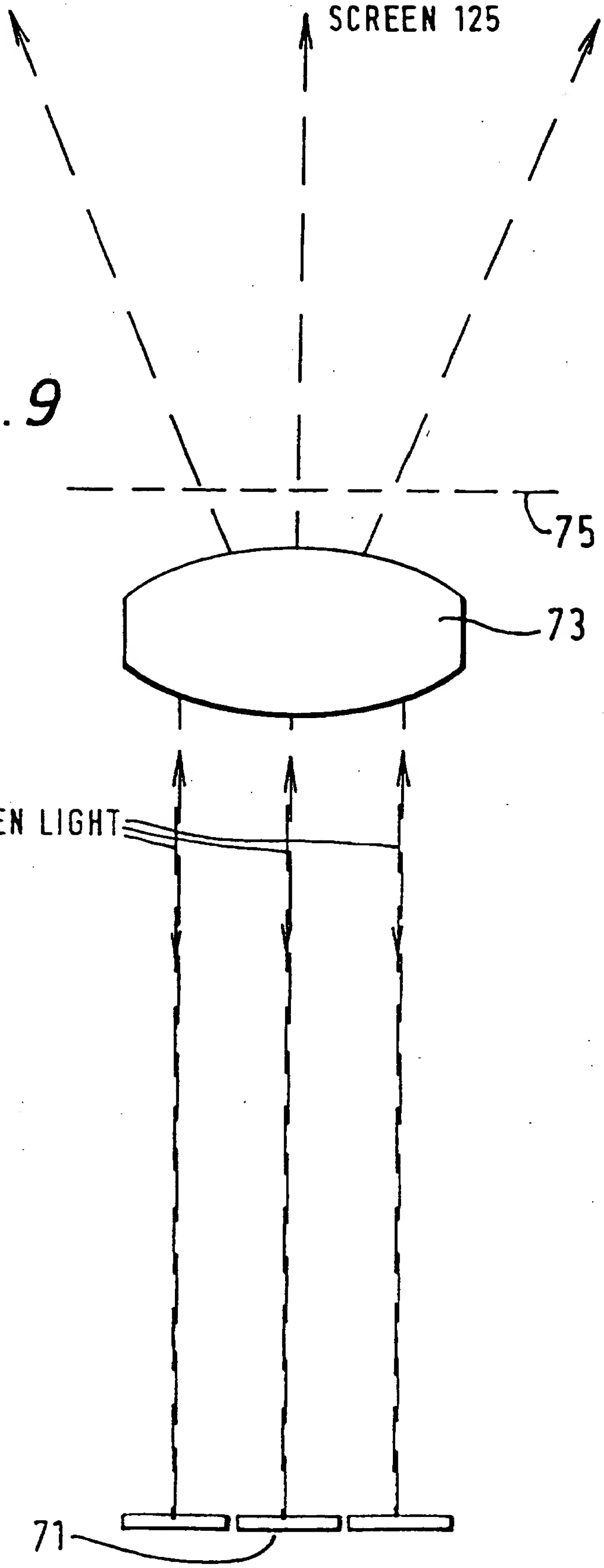


FIG.9

FIG. 10

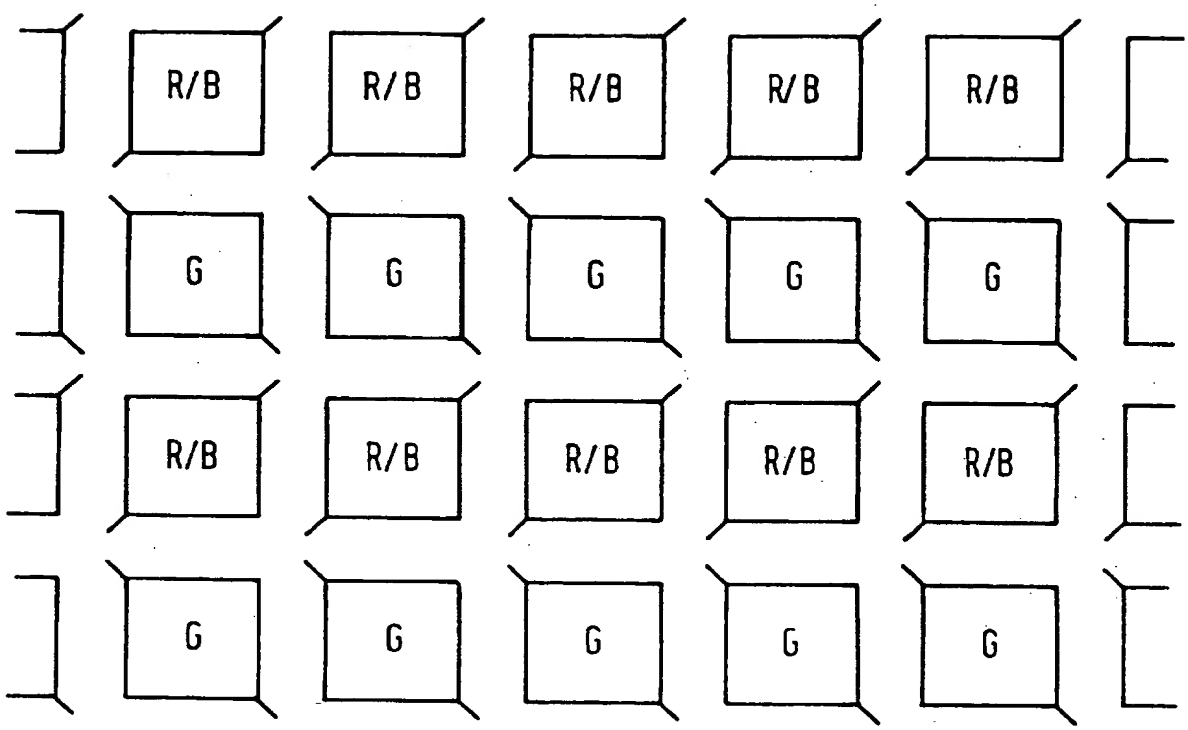

R/B
R/B
R/B
R/B
R/B
G
G
G
G
G
R/B
R/B
R/B
R/B
R/B
G
G
G
G
G

FIG. 11

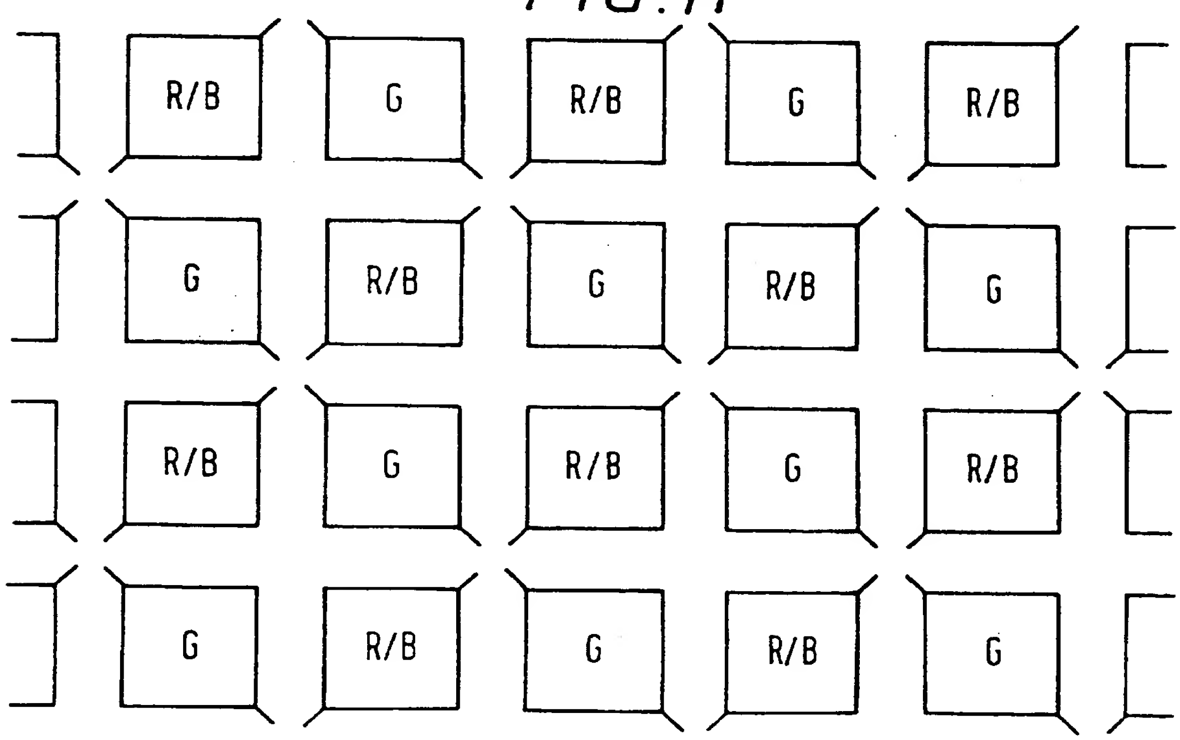

R/B
G
R/B
G
R/B
G
R/B
G
R/B
G
R/B
G
R/B
G
R/B
G
R/B
G
R/B
G

FIG. 12

R/B SEQUENCE GREEN	BB RR BB RR BB RR BB RR R B RR BB RR BB RR BB GG GG GG GG GG GG GG GG G G GG GG GG GG GG GG

FIG. 13

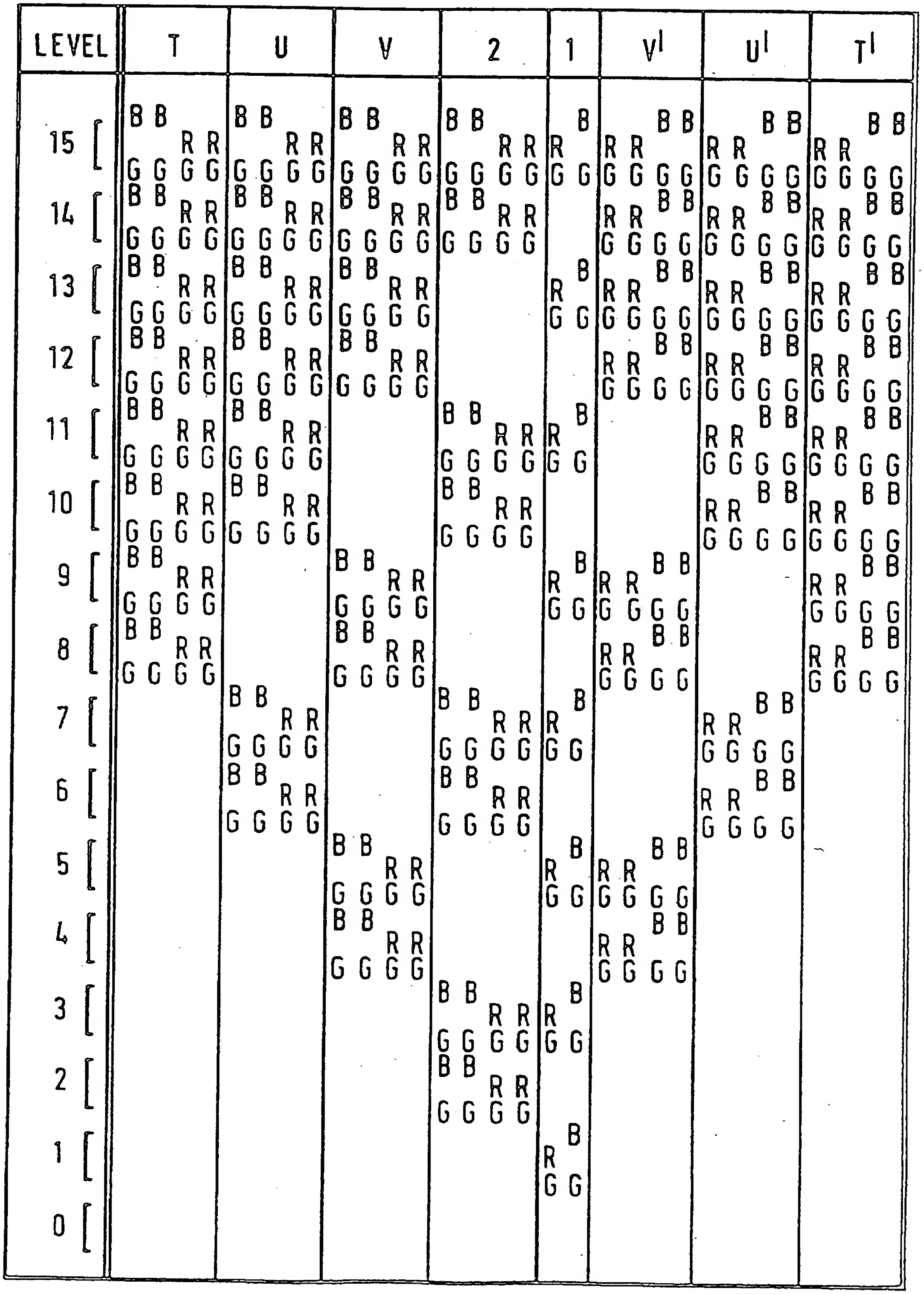


FIG.14

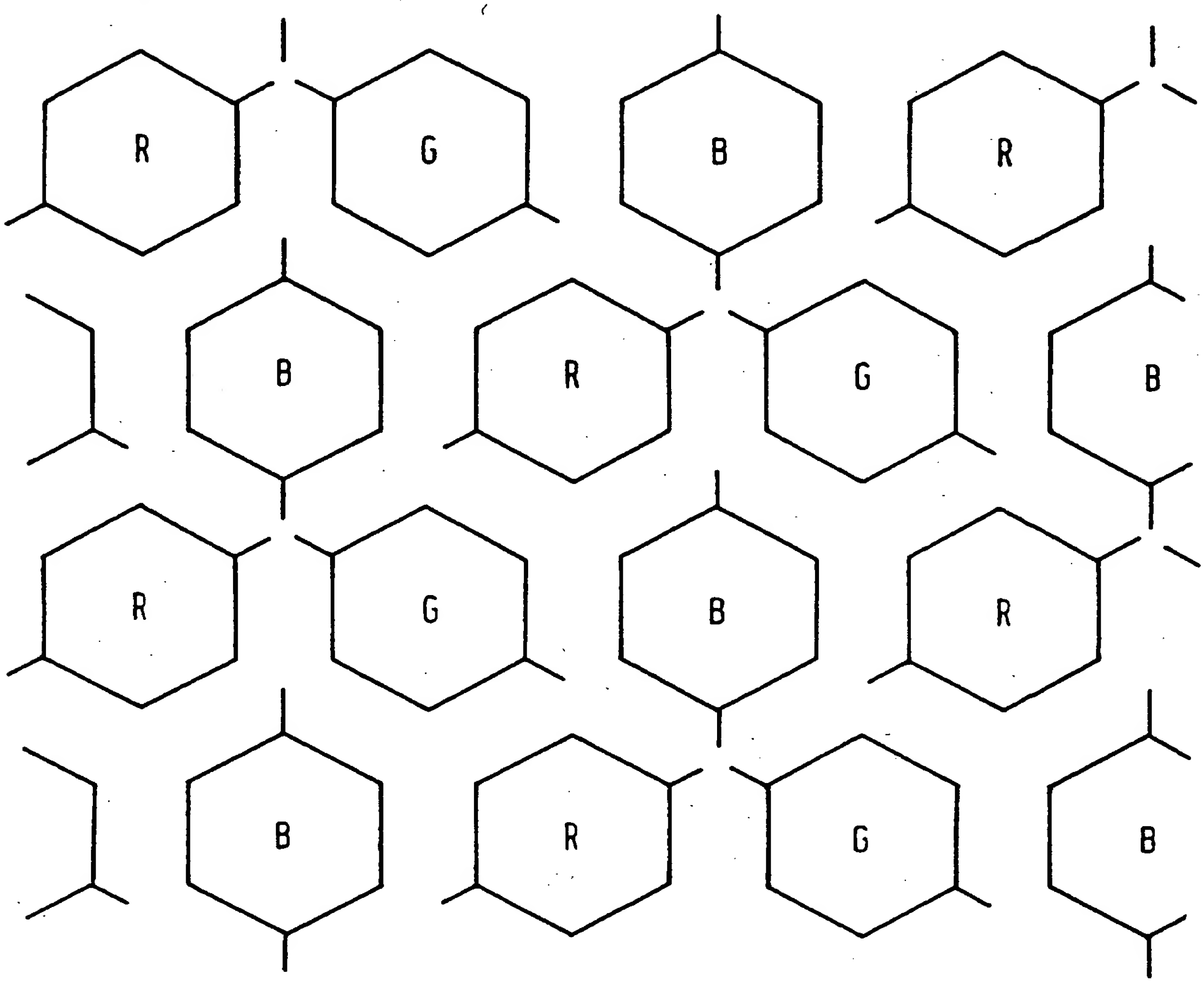


FIG.15

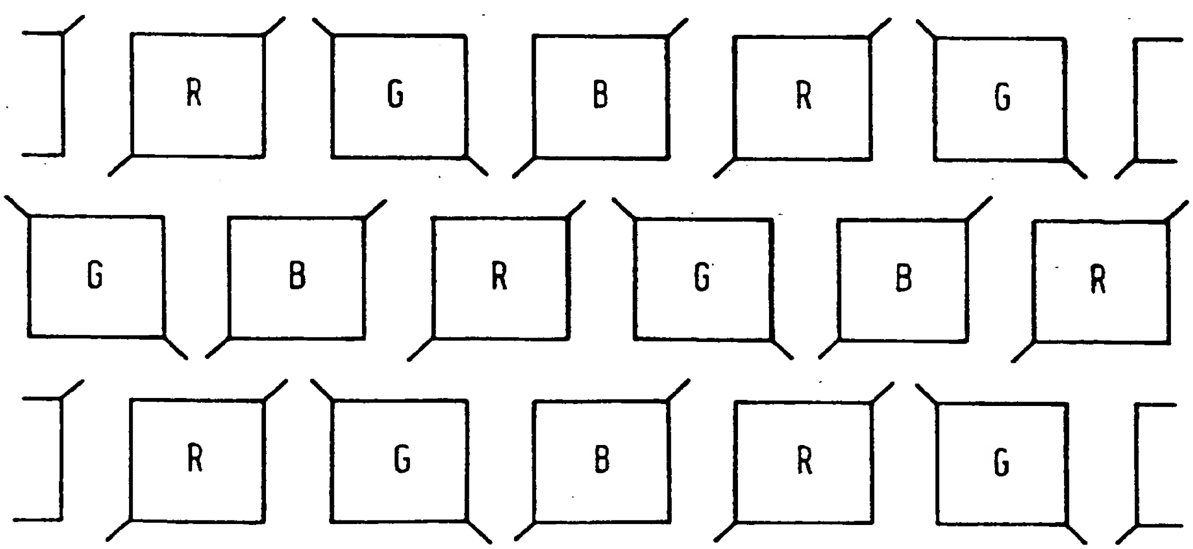
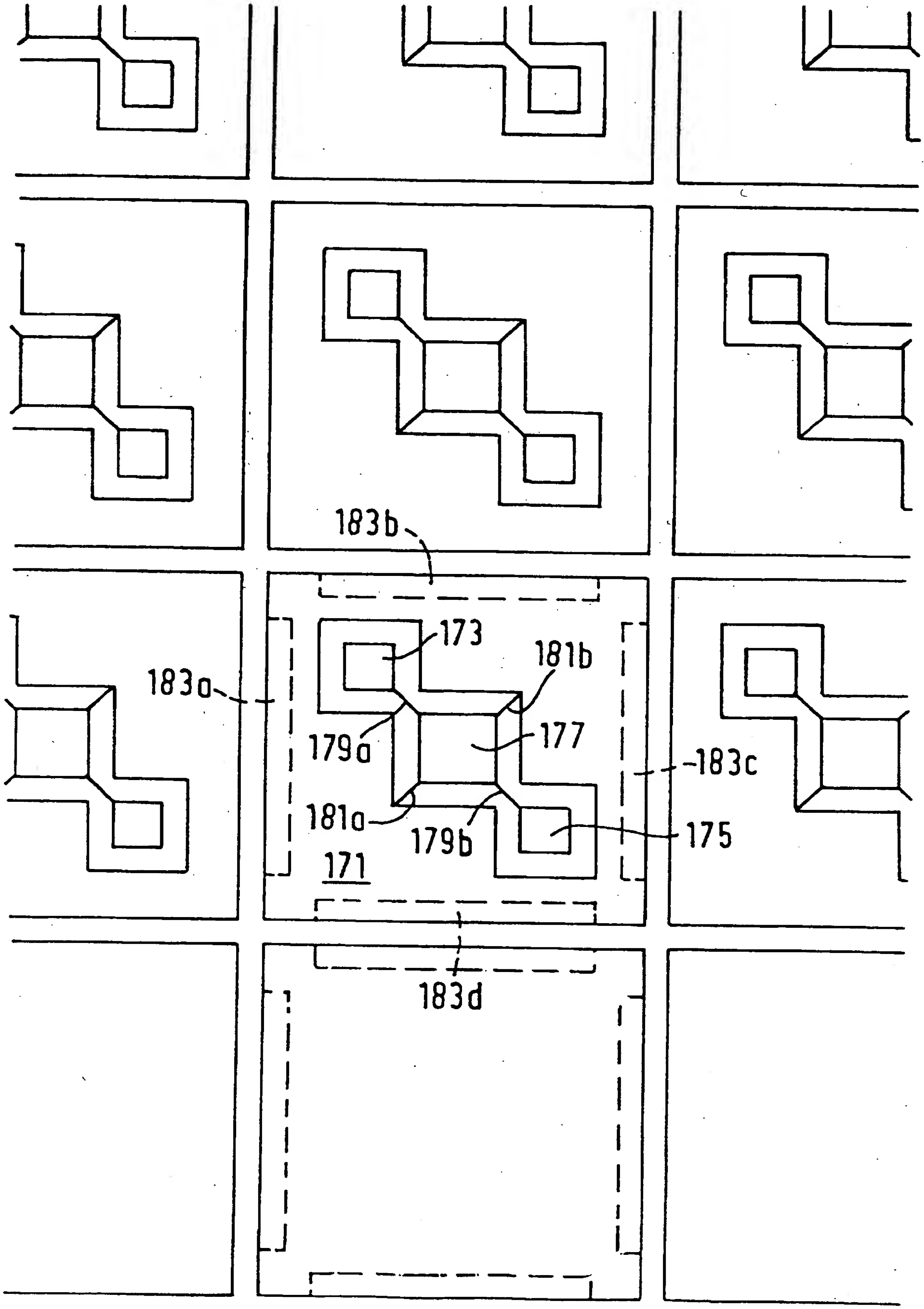


FIG. 17



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DISPLAY SYSTEM

This invention relates to display system and methods using one or more deformable mirror devices (DMDs). The invention has particular relevance to display system and methods for producing a colour display.

DMDs include an array of hinged mirror devices, each mirror device being mounted by a torsion element over a control electrode on a substrate. Applying an electric field between the mirror device and the underlying electrode causes the mirror device to pivot, switching the direction of light reflected from the mirror device either towards a projection lens system for projection onto a display screen, or onto a light dump. Thus by use of an array of mirror devices, each mirror device corresponding to a pixel of an image to be displayed and each mirror device being addressable by a formatted video signal, a spatially modulated light beam may be projected onto the display screen so as to display the image on the display screen.

The general operation of a DMD will now be described with reference to Figures 1 and 2 in which:

Figure 1 is a schematic diagram of part of a display system incorporating a DMD;

Figure 2 illustrates the operation of a mirror element in the DMD of Figure 1.

Referring to Figures 1 and 2, the reflection face of each DMD comprises a matrix of m x n separate deflectable mirrors M_{11} to M_{mn}. Each mirror M is mounted upon a pair of hinges 10 supported on an underlying substrate (not shown) such that the mirror rotates about an axis through one of the diagonals of the mirror under the influence of an electrostatic field applied by electrodes (not shown) mounted upon the substrate beneath the mirror M.

As can be seen in Figure 2 the mirrors M have three possible orientations, that is parallel to the plane of the matrix of mirrors, and at ± 10° with respect to the plane of the matrix. Thus for an incoming light beam at 20° to the normal to the matrix, where the mirrors M are tilted at +10° to the plane of the matrix, the light beam is reflected along the "ON" path into the entrance pupil of a projector lens (not shown in Figures 1 and 2) for projection onto the display screen (not shown in Figures 1 and 2). Alternatively, where the mirrors M are parallel or at -10° to the matrix, the light beam is reflected along one of the two "OFF" paths away from the lens into a light dump (not shown in Figures 1 and 2) in the form of a suitable light absorbing medium.

Referring now particularly to Figure 1, in order to vary the orientation of the mirrors M the matrix of deflectable mirror is connected to a driver circuit 11 which receives an electronic colour video signal from a control circuit indicated generally as 13. The driver circuit 11 is arranged to apply address signals to each of the mirrors M_{11} to M_{mn} as for example described in the applicants' earlier International Publication No. WO 92/12506 (the contents of which are incorporated herein by reference). The applied signals produce the necessary electrostatic fields to cause the required orientation of each mirror M. Thus each DMD matrix is capable of producing a spatially modulated beam representing a two dimensional image, those mirror images M which are tilted to the "ON" state appearing bright and those which are tilted to the "OFF" state appearing dark.

Connecting the mirrors into electrically separate groups, for example separate rows or diagonals as described in PCT Application WO 92/090965 (the contents of which are incorporated herein by reference) allows selected groups of mirrors within the DMD to be selectively reset or loaded with new data corresponding to the required mirror orientation.

In order to provide a colour display system, the system may include three separate DMDs, each DMD being

illuminated with light corresponding to one of the three primary colours (red, green and blue). Each DMD is energised with formatted video information corresponding to the colour of the illuminating beam. The spatially modulated light images produced by the three DMDs are then combined, to form a complete colour image on the display screen.

Such a system produces images of high brightness and quality, but is comparatively complex, expensive and requires stable convergence of the three spatially modulated beams whose registration may vary with factors such as temperature.

An alternative colour system uses a single DMD which is illuminated sequentially (usually at video frame rate) with light beams of the three primary colours. Formatted address signals are applied synchronously with the sequence of coloured light beams, such that sequential primary colour images are projected on the display screen. The sequence is fast enough such that the eyes of an observer viewing the resulting projected image on the display screen will integrate the sequential primary colour images on the display screen to see a complete colour image. The sequential three colour illumination is usually effected by means of a so called "colour wheel" which is a rotating disc bearing colour filters,

the rotation being synchronised with the sequence of the video signals.

Such a colour wheel system produces images of medium brightness relatively cheaply. The system does however depend upon mechanically moving parts which are subject to wear, asynchronous operation etc and the disadvantage that colour fringing will be apparent on rapidly moving objects in the projected picture.

It is an object of the present invention to provide a colour display system in which the disadvantages of prior art systems are at least alleviated.

According to first aspect of the present invention there is provided a colour display system including a deformable mirror device in which chosen mirrors may be arranged to selectively direct light of chosen wavelengths towards a display screen.

According to a second aspect of the present invention there is provided a display system including a deformable mirror device comprising an array of deflectable mirrors, each mirror being deflectable between at least two different orientations, and means for illuminating each mirror device with light within at least two different wavebands, such that light within the first waveband is

deflected from the mirror elements in the first orientation towards a display screen and light within the second wavelength band is reflected from the mirrors in the second orientation towards the display screen.

According to a third aspect of the present invention there is provided a display system incorporating a deformable mirror device comprising an array of mirror elements wherein the mirror elements are divided into groups, mirrors within each group being arranged to direct light within different wavelengths onto a display screen.

A number of embodiments of the invention will now be described, by way of example only, with reference to the accompanying drawings in which:

Figures 1 and 2 illustrate the general operation of a DMD as has already been described;

Figure 3 is a schematic diagram of a display system in accordance with a first embodiment of the present invention;

Figure 4 illustrates the hinge orientations of the mirror devices incorporated in the DMDs of Figure 3;

Figure 5 compares the light projection sequence of the display system shown in Figure 3 with that of a system using a colour wheel;

Figure 6 illustrates a possible grey scale bit weight distribution scheme for use with the display system of Figure 3;

Figure 7 is a schematic illustration of a display system in accordance with a second embodiment of the invention;

Figure 8 is a schematic diagram of a display system in accordance with a third embodiment of the present invention;

Figure 9 corresponds to the view of Figure 8 showing illumination of the DMD incorporated in the system of Figure 8 by green light only;

Figure 10 illustrates the hinge arrangements of the mirror devices incorporated in the DMD in the system of the third embodiment;

Figure 11 shows an alternative DMD array used in the third embodiment;

Figure 12 illustrates a possible light projection

sequence for full illumination of the DMD array used in the third embodiment;

Figure 13 illustrates a possible grey scale bit weight distribution scheme for use with the display system of the second embodiment;

Figure 14 illustrates a DMD configuration used in the fourth embodiment of the present invention;

Figure 15 illustrates an alternative DMD configuration used in the fourth embodiment of the present invention;

Figure 16 illustrates the operation of a mirror element incorporated in the DMD used in the fourth embodiment of the present invention; and

Figure 17 is a schematic illustration of a DMD used in a fifth embodiment of the present invention.

<u>FIRST EMBODIMENT OF THE INVENTION - TIME MULTIPLEXED COLOUR DISPLAY SYSTEM</u>

The description in relation to Figures 1 and 2 gives an overview of the general operation of a DMD.

In the first embodiment of the invention to be described

two DMDs are arranged to direct sequentially blue, green and red light onto a display screen without the need for, for example, a colour wheel.

Turning to Figure 3, the first embodiment to be described includes two DMDs 31, 33 and three different light sources 35, 37, 39 each effective to produce light of a different colour, that is in the blue, green and red wavelength bands. The blue light source 35 is arranged to direct blue light directly onto the DMD 31. The green and red light sources 37, 39 are arranged to direct light onto the second DMD 33 which acts as a switch to direct either green or red light onto the first DMD 31.

Thus when the mirrors within the DMD 33 are in a first orientation shown in full lines in Figure 3, green light will be directed onto the first DMD 31, whilst the red light incident on the DMD 33 will be reflected to a light dump (not shown). In the second orientation of the mirrors within the DMD 33 shown as dotted lines in Figure 3, the red light is directed onto the first DMD 31 whilst the green light is directed away from the first DMD 31 towards a further light dump (not shown).

Turning now also to Figure 4, each mirror of the DMD 31 is arranged with its hinges at alternate corners of the mirror, and is responsive to which ever of the green or

red light is directed by the DMD 33, together with the blue light. Each individual mirror of DMD 31 has three effective states. In state I as shown by the dotted lines in Figure 3, blue light is directed to the projection lens 41 for projection onto a screen indicated as 125 in the figure. In state III as shown by the full lines in Figure 3, light of the colour selected by DMD 33 is directed to the projection lens and thence to the screen. In state II, mid-way between states I and III, the mirrors are parallel to the plane of the DMD array 31, and neither light from the blue source, nor light selected by the DMD 33, is directed to the projection lens 41 and thence to the screen. State II provides in effect a "black" state, when no light reaches the screen from a mirror in that state. The proportion of the total time that each mirror is in state I controls the amount of blue light falling on each pixel of the screen. The proportion of the total time that each mirror is in state III whilst DMD 33 is reflecting red light to DMD 31, controls the amount of red light falling on each pixel of the screen. Similarly the proportion of the total time that each mirror is in state III whilst DMD 33 is reflecting green light to DMD 31, controls the amount of green light falling on each pixel of the screen.

Thus in this embodiment, due to the two directions of incident beams on the DMD 31, spatially modulated blue

light alternates with either spatially modulated red light or spatially modulated green light along the "ON" path to the projection lens 41. The mirrors of the DMD 31 not only select between red/green and blue light but control the amount of light of each colour falling on the individual pixels for the projected image on the screen. This contrasts with the function of the mirrors of the DMD 33 which only act as a switch for switching between red and green light and do not effect the amount of light projected onto the screen. The address system 11 indicated in Figure 1 must be modified to provide appropriate address signals to the DMD31 to control the switching of the mirrors between their blue active states and their red/green active states, together with providing "grey scale" modulation as will be described hereafter. The address system 11 must also control the switching of the DMD 33 between reflecting red and green light towards DMD 31.

Light on the "ON" path from the primary DMD 31 will be sharply focused by the projection lens 41 onto the screen. However, it will be appreciated that the second DMD device 33 should be positioned so as to be out of focus such that an image of the DMD 33 is not projected onto the projection screen. This avoids any possibility of a beat pattern produced by the combination of the two DMDs 31 and 33, and the image of any blemished pixels in

DMD 33 being projected onto the final image.

Turning now to Figure 5, this figure illustrates the differences between the colour time sequences for maximum illumination of any mirror M in the primary DMD 31 in the first embodiment of the invention and a colour wheel system as used in prior art colour display systems.

The upper sequence shown in Figure 5 shows the three primary colours, blue (B), green (G) and red (R) being projected sequentially onto a single DMD. For the sake of clarity a time sequence corresponding to a 4-bit input video signal, having 15 sets of blue (B), green (G) and red (R) illumination levels is shown rather than the 255 sets of illumination levels corresponding to an 8-bit input video signal which would normally be used. Normally the total sequence will repeat at a television field rate, that is fifty times per second. For 625 line television, misregistration of about 0.002 screen widths between the green and red signals is about the largest that can be tolerated. When, however, an observer is following the motion of an object in the image, a delay of a third of a field or 6.67 ms between the green and red images would correspond to a spatial misregistration on the image of 0.002 screen widths for an image of an object such as a racing horse having a speed of motion over the image of a screen width in 167 fields or 3.34

seconds. Motion at a higher speed will cause a visual sense of colour misregistration when the eye of the observer is following the motion.

The lower part of Figure 5 shows a sequence achievable by the embodiment of the invention illustrated in Figures 3 and 4. As can be seen in this sequence, there is now no long run of blue, green or red light illumination levels which leads to the undesirable effects exhibited by a colour wheel system.

As described above, DMDs are digital devices, that is each mirror of the DMD is effective to switch the light passing from the mirror to the displayed image either "ON" or "OFF" so as to produce either full intensity red, green or blue pixels or "white" pixels on the displayed image. It is, however, possible to display grey scale images using a time multiplexing scheme by controlling the time for which each mirror of the DMD is in an orientation such that light from the mirror arrives at the displayed image, and using the integrating response of the eye of an observer who will perceive a grey scale image from the mirror. Such an arrangement is, for example described in our copending International Application WO92/12506 (the contents of which are incorporated herein by reference). For an 8-bit input video signal, the eight time periods

within each display frame period are of different lengths corresponding to bits D0 to D7 of the input video signal. The length of the time period corresponding to the least significant bit (LSB), or D0 in the input signal for any particular frame, is set at a predetermined value, the duration of the time period corresponding to the next to the least significant bit (D1) being twice as long as that corresponding to the LSB, and so on. Thus, the length of the time period corresponding to the most significant bit (MSB) or D7 in the input signal is 128 times that corresponding to the LSB.

Provided that all the time periods are included within a display frame period of less than around 20 msecs duration, the eyes of an observer will integrate the periods and respond as if to a single period having a level of brightness corresponding to the binary signal value. All the bits of the same significance are entered into the elements of the array effectively simultaneously. At the end of each sub-frame period corresponding to a single bit of the input signal, a single reset signal is supplied to all the elements of the array simultaneously in order to switch the elements, either into a rest position in some systems as for example described in our copending application WO 92/12506, or into the state determined

by the next bit signal in other systems.

In order to improve the temporal balance of bits over each display frame, the higher significance bits may be split as described in our copending International Patent Application WO 94/09473 (the contents of which are incorporated herein by reference).

Referring now to Figure 6, this figure shows a bit weight distribution scheme for displaying grey scales in which green, red and blue light is sequentially displayed using the first embodiment of the invention as illustrated in Figures 3 and 4. For the sake of clarity only light levels of between 0 and 15 units are shown, this again corresponding to a 4-bit input video signal. It will be appreciated however that in order to display a full grey scale normally a range of light levels of between 0 and 255 units would be used corresponding to an 8-bit input video signal.

In Figure 6, the central column marked "1" illustrates a time subframe for displaying the minimum light level of 1 unit corresponding to the least significant bit i.e. DO or LSB. The maximum light level of 15 units is split into eight time subframes T, U, V, 2, 1, V', U', T' which are equal in duration except for the 1 unit subframe which has half the duration of the other subframes. The

subframes are used in pairs: T & T′, U & U′ and V & V′. The two parts of a pair carry the same information and are temporally balanced by being placed as mirror images about the temporal centre of the frame as described in WO 94/09473. It can be seen from Figure 6 that these three pairs of subframes taken together with the 2 units subframe always represent a total illumination level equal to the level represented by the binary coded bits D1, D2 and D3.

As explained in our co-pending International Application No. WO94/09473 (the contents of which are incorporated herewith by reference) the effect of such bit splitting is to minimise flicker.

As can be seen from Figure 6, the positions in the matrix for blue, red and green light pulses are symmetrical for the two halves of the matrix, ensuring that the mean time for all pairs of split bits and for red, green and blue light within the pairs of split bits are identical within the time frame. Whilst, at the low level light levels 1 and 2, the timing is not symmetrical over the time frame, the small mistiming will be less noticeable subjectively particularly at these low brightness levels.

Whereas figure 6 shows subframes T, T′, U, U′, V and V′ as all being of equal length, the important feature is

that however many pairs of subframes there may be, for each pair of subframes, the two parts comprising the pair are equal in length one to the other, and are placed symmetrically in time within a television field.

It will be appreciated that where a colour wheel is used to provide sequential runs of blue, green and red light, it is not possible to obtain such a symmetrical pattern of light pulses over each time frame.

SECOND EMBODIMENT OF THE INVENTION - TIME MULTIPLEXED COLOUR DISPLAY SYSTEM

The second embodiment is an adaptation of the first embodiment using two secondary DMDs 61, 63 to switch between the red, blue and green light directed onto a primary DMD 65, all three DMDs 61, 63, 65 being addressed in parallel by an address system 67 to ensure synchronous switching of the three DMDs.

Figure 7 illustrates schematically the switching arrangement. A first DMD 61 operates in an analogous manner to the DMD 33 in Figure 3 and is addressed by both red and blue light from red and blue light sources to selectively switch either the incoming blue light or the incoming red light to a second secondary DMD 63, the unwanted light being directed to light dumps (not shown).

The second secondary DMD 63 is addressed by either the blue or red light selected by the first DMD 61 and also green light from a green light source. The second DMD 63 is then effective to select either the blue or red light previously selected by the first DMD 61 or the green light and direct this to a third DMD 65, the unwanted light being directed to a light dump.

The third DMD is thus addressed by either blue light, red light or green light, the mirror elements of the third DMD 65 being effective to direct spatially modulated light towards the projector lens 125 for projection on the projector screen, the unwanted blue, red or green light being directed towards a light dump dependent on the video signal used to address the address system 67.

It will be seen by use of this particular configuration the primary DMD 65 is able to operate in a manner of conventional DMDs as illustrated in Figure 2. In other words, the DMD 65 will only be effective to direct light via the projector lens to the screen 125 when the mirrors are at +10° to the plane of the DMD array. When the mirrors are at -10° to the plane of the DMD array, light incident on the mirrors of the primary DMD 65 will be directed along the "OFF" path shown in Figure 2 towards the light dump.

It will be appreciated that whilst this particular embodiment utilizes three DMDs, the system will have the same advantages in relation to colour wheels as described with respect to the first embodiment. In particular it is possible to synchronize the operation of the three DMDs 61, 63, 65 electronically. Furthermore, long runs of red green or light blue necessitated by a colour wheel are avoided as explained in relation to Figure 5 and address schemes as illustrated in Figure 6 are possible.

THIRD EMBODIMENT - PARTIALLY TIME MULTIPLEXED SYSTEM

In the third embodiment to be described, the red and blue light is again time multiplexed as in the first embodiment, but the system includes a single DMD in which half the mirrors are dedicated to incoming green light, with the other half of the mirrors M being alternatively dedicated to alternately red and blue light on a time multiplexed basis.

This arrangement is achieved by the use of three separate light sources for projecting green, red and blue light as illustrated in Figures 8 and 9 and one DMD array 71 as, for example illustrated in Figure 10.

As seen in Figure 8, the red and blue light is directed from alternate sides of the DMD array 71 such that the

"ON" path for either the red or the blue light is directed onto the projection lens 73 for onward projection onto a display screen (not shown) dependent on the orientation of the mirrors within the DMD 71.

As seen in Figure 9, the green light is directed onto the mirrors of the DMD 71 such that the mirrors dedicated to green light deflect the incoming green light through an angle perpendicular to the plane of the paper carrying the figure, the "ON" path for light reflected from the mirrors of the DMD 71 being towards the projection lens 73, the "OFF" path being towards a light dump (not shown).

Figure 10 shows an example of a suitable mirror configuration for the DMD array 71. As shown in Figure 10 the hinges for the mirrors are all at the diagonal corners of the mirrors, with the mirrors dedicated to green light having hinges at 90° to those of the mirrors dedicated to either red or blue light. The mirrors used for the red and blue light are arranged in lines with the intervening lines being used for the mirrors used for the green light.

It will appreciated that in the mirror configuration illustrated in Figure 10, because two rows of mirrors are needed to reflect light of all three colours the vertical

resolution for light of any colour will only be the half of that of the horizontal resolution. This feature is advantageous when used in conjunction with an amorphic lens in conjunction with the projector lens 73. Such an amorphic lens is shown schematically in Figures 8 and 9 as 75 and may be designed to provide a 2:1 compression of the spatially modulated beam in a vertical direction on the projection screen compared to the horizontal direction. For a projected aspect ratio of 16:9 on the screen, the aspect ratio of the element array on the DMD 71 will be 8:9. A higher illumination efficiency can be obtained more readily for a nearly square DMD array than would be the case for a DMD array in which the horizontal and vertical dimensions differ significantly.

It will be appreciated that the projector lens may itself be made amorphic to achieve the same effect.

Turning now to Figure 11, this figure shows an alternative mirror configuration for use in the second embodiment. In this mirror configuration the mirrors dedicated to green light and the mirrors dedicated to either red or blue light have been arranged in diagonal lines to give equal horizontal and vertical resolution at the expense of diagonal resolution. It has been shown that this is a reasonable match to human visible perception, as explained for example the SMPTE Journal

Vol. 97, No. 5, pages 374 to 377 "Enhancing Television - An Evolving Scene" by John L E Baldwin, published May 1988. As explained in this article, for a person with normal eye sight, horizontal and vertical gratings will remain visible at a substantially greater distance than that at which the diagonal grating has become uniformly grey.

Turning now to Figures 12 and 13, these figures illustrate timing sequences for the red/blue and green light within a single TV frame or field.

Figure 12 illustrates the projection of maximum brightness light along the "ON" path to the projection screen. In Figure 12 gaps have been left for the sake of clarity. It will be appreciated however that for maximum brightness levels there will be no gaps, the green illumination being continuous. The blue and red light pulses are uniformly distributed across the bit frame.

As can be seen from Figure 12, as the mirrors which are arranged to reflect exclusively green light are used for the same duration as the total time for which red and blue light is reflected, the display system will have an excess capacity for green light. This excess may be removed by a neutral density filter in the green light path, or preferably by decreasing the spectral width of

the incident green light.

It will be appreciated that in some cases where the light source is deficient in, for example red wavelengths it will be preferable to make the mirrors which are receptive to only one colour band receptive to the red light instead of green light as illustrated in Figures 10 and 11. Thus the wavelength band which is deficient in the incident light beam may be at least partially compensated.

Figure 13 illustrates a possible bit weight distribution scheme for displaying grey scale in a partially time multiplexed system such as this third embodiment of the invention. It will be seen that as in the bit weight distribution scheme shown in Figure 6 for the totally time multiplexed system of the first embodiment, the red/blue sequence is more or less symmetrical between the two halves of the bit frame at least for higher illumination levels. This means that the mean timing of the light pulses for the red and blue light will be identical, as well as being identical to the mean timing of the light pulses for the green light.

FOURTH EMBODIMENT - FULL COLOUR SIMULTANEOUS ILLUMINATION SYSTEM

In the fourth embodiment of the invention to be described, the DMD is arranged with three groups of mirror elements each dedicated to light of a different colour. The DMD is illuminated using three different colour light sources as for example shown in Figures 8 and 9.

Turning now to Figure 14 this Figure shows an example of a suitable mirror configuration comprising an array of hexagonal mirrors, each mirror having flexure hinges at opposite corners of the hexagon. The angle of the line of the hinges of each mirror controls which of the three primary colours, i.e. red, blue or green light can be reflected into the entrance pupil of the projection lens. Thus as shown in Figure 14 the hinge lines for each of the red (R), green (G) and blue (B) mirrors vary by 60°. The three illuminating beams of red, green and blue light are angled down on the plane of the array, such that the projections of the three light beams on the plane are separated by 60°.

In an alternative use of the same mirror configuration, the three incident light beams can be separated by 120°

as each of the mirrors in Figure 14 can be arranged to tilt in the opposite sense about their hinge lines.

Turning now to Figures 15 and 16, these figures illustrate a further alternative embodiment of a mirror array having three sets of mirrors, each set of mirrors being dedicated to red, green or blue light. As can be seen from Figure 15 the hinge lines for the red and blue mirrors are parallel along one diagonal of the mirrors, whilst the hinge lines for the green mirrors are set at 90° along the opposite diagonal to the direction of the hinges for the red and blue mirrors.

In analogous fashion to the mirror arrangement illustrated in Figures 10 and 11, the blue and red mirrors are arranged to produce reflected light along the "ON" direction with the red and blue mirrors in opposite deflection states about their hinge lines.

Referring now also to the mirror orientations shown in Figure 16, the red light is incident along the dotted path at -20° to the normal to the array, such that the mirrors must rotate to the -10° position relative to the plane of the matrix to the position shown dotted in Figure 16. The blue light is incident along the incident light path at +20° to the normal to the array such that

the mirrors must rotate to the +10° position relative to the plane of the matrix. In other words the mirrors must rotate clockwise for the red light and anticlockwise for the blue light.

It will be appreciated that any suitable mirror configuration may be used for interleaving the red, green and blue mirrors within the DMD in order to achieve a full colour simultaneous illumination system.

FIFTH EMBODIMENT

In an alternative embodiment the mirrors of the DMD array may be arranged such that they are deflectable in more than the two directions illustrated in Figure 16, so that each mirror may be used to deflect different coloured light in three different directions. Such a mirror configuration may for example take the form of a "mushroom" configuration in which each mirror of the DMD is supported by a central post.

Figure 17 shows an example of a DMD array receptive to incoming light in at least three directions. The DMD array comprises an array of mirrors 171 in Figure 17 each suspended by two posts 173, 175 which are each rigidly mounted to the substrate for the array (not shown). A central region 177 is attached to the two posts 173, 175

via flexure pivots 179a, 179b which permit pivoting of the central region 177 relative to the two posts 173, 175 about a diagonal axis through the central region 177.

The central region 177 is itself attached to the main portion 171 of the mirror element via two other flexure pivots 181a, 181b which permit pivoting of the mirrors about the opposite diagonal of the central region 177 to the axis of rotation of the central region 177 relative to the fixed posts 173 and 175.

It will be seen that the two pairs of flexure pivots 179a, 179b and 181a, 181b make it possible for the mirrors 171 to tilt towards the north, south, east and west directions, intermediate tilts also being possible. Beneath each mirror 171 on the underlying substrate there are provided four electrodes 183a, 183b, 183c, 183d. Electrostatic fields applied to chosen ones of the electrodes 183a - 183d cause deflection of the mirror 171 in the chosen direction.

Thus in use of the array shown in Figure 17, light from red, green or blue light sources illuminate the DMD continuously at angles of 20° to the normal to the plane of the array but angled down from different directions, for example from east, south and west directions. Appropriate electrostatic fields are applied via the

chosen ones of the electrodes 183a, 183b, 183c, 183d so as to reflect light from either the red, green or blue light source to the entrance pupil of the projection lens 125. The amount of time which light of a particular colour is directed towards the entrance pupil of the projector lens will control the colour and brightness of the corresponding pixel on the projector screen.

It will be appreciated that only three of the four electrodes 183a, 183b, 183c and 183d is needed in principle to direct light of the appropriate colour towards the projection lens. However, the fourth electrode is desirable to deflect the mirror to a position where no light is reflected to the entrance pupil of the projector lens, i.e. so as to define a "rest" position for the mirrors 171.

It will be appreciated that in Figure 17 the flexure pivots 179a, 179b and 181a, 181b have been described as if they are in the plane of the mirrors. This is merely for ease of description, and in principle the mirror surface 171 will extend over the flexure pivots so as to increase the optical efficiency of the array, and also to prevent light being scattered from parts of the surface of the DMD array.

It will be appreciated that many other mirror

configurations other than the mirror configuration shown in Figure 17 is possible. For example the mirror elements may take the form of hexagonal mirrors which are able to pivot about three different axes.

TWO OR MORE THAN THREE COLOUR CHANNEL DISPLAY SYSTEMS

It will be appreciated that whilst a three colour channel system employing red, green and blue light will be particularly useful, the invention also covers display systems in which for example only two different colours are displayed. Alternatively the input light may be split into different configurations other than the three primary colours red, blue and green. Input light may for example be the primary subtractive colours of cyan, magenta, and yellow.

It will also be appreciated that where pulse width modulation is used to display grey scale as described above, in order to use the unused time between the display time bits, a "bit stuffing" technique may be used to fill in or "stuff" parts of higher order bits in the unused time using a technique as described, for example in the applicant's copending International Application GB94/00819 (the contents of which are incorporated herein by reference).

CLAIMS

1. A display system comprising a deformable mirror device comprising an array of deflectable mirrors, and means for directing light onto the array of deflectable mirrors wherein light within different wavelength bands are directed along paths to the deformable mirror device which are at least partially separate so as to enable the deflectable mirrors to direct light within chosen wavelength bands towards a display surface.

2. A display system according to Claim 1, wherein at least a selection of the mirrors are deflectable between at least two different orientations, and the display system includes means for illuminating each of the selection of mirrors with light within at least two different wavelength bands, the selection of mirrors being arranged such that light of the first wavelength band is reflected from the mirrors whilst in the first orientation towards the display surface, and light in the second wavelength band is reflected from the selection of mirrors whilst in the second orientation towards the display surface.

3. A display system according to Claim 1 in which mirrors within the array which are not arranged to reflect light within at least two different wavelength bands are arranged in diagonal patterns across the array.

4. A display system according to Claim 1 wherein the array of deformable mirrors is divided into groups of mirrors, each mirror within each group of mirrors being arranged to direct light within one or more different wavelength bands onto the display surface.

5. A display system according to any one of the preceding claims, including a second deformable mirror device arranged to direct light from two separate light sources sequentially onto the mirrors of the first deformable mirror device.

6. A display system according to Claim 5 including a third deformable mirror device effective to direct light from two separate light sources sequentially onto the mirrors of the second deformable mirror device so as to constitute one of the separate light sources for the second deformable mirror device.

7. A display system according to Claim 4, in which the mirror elements are arranged such that the number of mirror elements effective to reflect light within a particular wavelength band is increased relative to that of the other wavelength bands.

8. A display system according to Claim 7, wherein the means for directing light comprises a multi wavelength

light source and the particular wavelength band corresponds to a wavelength band in which the light produced by the light source is deficient.

9. A display system according to Claim 7, in which the particular wavelength band is that of green light.

10. A display system according to Claim 4, in which the groups of mirrors are arranged so as to increase the aspect ratio in one direction across the array and including an amorphic lens effective to increase the size of the light beam projected on the display surface in the direction orthogonal to the direction in which the aspect ratio is increased.

11. A display system according to Claim 2, in which all the mirrors are arranged to deflect light within different wavelength bands in different directions.

12. A display system according to Claim 2, in which the selection of mirrors are arranged to deflect light within three different wavelength bands in three different directions.

13. A display system according to Claim 2, wherein at least some of the mirrors are arranged to deflect light of different wavelengths in two different directions, the

axes of rotation of the mirror for the two different deflection directions being substantially orthogonal.

14. A display system substantially as hereinbefore described with reference to Figures 3 to 17 of the accompanying Figures.

Application No:	GB 9524259.0	**Examiner:**	R. F. King
Claims searched:	All	**Date of search:**	7 March 1996

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Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.O): H4F[FCW]

Int Cl (Ed.6): H04N 5/74, 9/31

Other: ONLINE DATABASE: WPI

Documents considered to be relevant:

Category	Identity of document and relevant passage	Relevant to claims
A	EP 0 391 529 A2 [TEXAS INSTR.] See whole disclosure	1
A	US 5,287,096 "	"
A	"Mirrors on a chip" pp27/-, IEEE SPECTRUM NOVEMBER 1993, See col. 1, p 27, 9 lines from bottom, 'Color may be added in two ways, by a color wheel or by a three-DMD setup in evelopment'	1

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